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INDUSTRIAL APPLICATION OF GAS TURBINES

Gas Turbine Application from a Kyoto Perspective

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Author Biography

John Barrie graduated from the University of Calgary in Mechanical Engineering. John is currently an Engineering Manager for a large oilsands project near Fort McMurray and supervises a multi-disciplinary team in the engineering required for the Utility and Offsites portion of this facility. Earlier in his career with Fluor he was the Section Head of Rotating Equipment and supervised engineers in the application and selection of large equipment such as compressors, pumps and turbines. He has worked in Europe, the Middle East and the US in a number of roles with Fluor. Prior to Fluor, he worked with Worthington and Westinghouse.

John is closely associated with one of the working groups of the International Energy Agency (IEA) Greenhouse Gas Committee based in the UK. This committee continues to explore advancements in carbon dioxide removal using solvents. John also served as the Industry Representative on the Management Committee of the International CO_2 Test Centre. He continues to participate in Natural Resources Canada workshops related to CO_2 capture and has facilitated, and made presentations, at workshops for the CO_2 Capture & Storage Technology Roadmap sessions.

ABSTRACT

Canada is a signatory of the Kyoto Accord and is currently reviewing options to reduce Greenhouse Gas (GHG) emissions by 6% below 1990 levels. Fossil fuels in transportation, power generation and other industries generate the major share of greenhouse gases such as carbon dioxide and methane. It is important to reduce these emissions at the source by various means, or to capture and dispose off these gases, to prevent them from entering the atmosphere and contributing to global warming. Several industry sectors will be required to make significant changes to ensure compliance, and this compliance needs to be done in the year 2008-2012 time frames in order to meet Canada's Kyoto commitments. This paper discusses methods to reduce GHG emissions and the role the gas turbine plays in power generation to ensure future compliance.

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GAS TURBINE APPLICATION FROM A KYOTO PERSPECTIVE

The Kyoto Accord is considered a major step for politicians, scientists, and environmentalists who had recommended that urgent action be taken to mitigate the impact of Global Warming. Catastrophic events such as prolonged heat waves in various parts of the world, droughts, melting glaciers, and rising ocean levels, have caused alarm in a number of countries and communities. Many believe these events are due to man-made emissions which have caused a sharp rise in the earth's temperature in the last century. The Accord, although a landmark event, has not been welcomed by some countries and industries who feel that limiting carbon emissions would have a detrimental impact on their economies. Some of those who disagree with the Accord believe (or are of the opinion) that there has not been a conclusive link established between man-made greenhouse gas (GHG) emissions and global warming.

The Accord has now been signed by the minimum number of countries required to make this International Law, and it is now necessary for industry to explore and apply appropriate technologies to comply with Kyoto requirements.

THE KYOTO ACCORD

The 1997 Protocol required developed countries to reduce their greenhouse gas emissions from a baseline measurement in 1990. The GHG reductions would come into effect in the 2008 to 2012 time frame. The GHG reduction ranges from 8% for the European Union, 7% for the US (had they participated) and 5.8% for Canada. Some countries, like the Commonwealth of Independent States (the former Soviet Union), would see no net reduction from 1990 levels, and others, like Australia would see an 8% increase. The Kyoto Accord required a minimum of 55 countries, representing a total of 55% of greenhouse gas emissions, to ratify the treaty. China and India were not required to participate since their economies are currently growing, but will be required to participate after the initial 2008-2012 period.

THE POLITICS

The present Accord evolved over the last two decades after meetings had been held with government representatives and scientists from several countries. In 1992 a summit on global warming was held in Rio de Janeiro and in later years at Marrakesh, Berlin, New Delhi and other venues. The Kyoto Summit in 1997 was attended by representatives from several countries, and, at this Summit, the Kyoto Protocol was signed. Ratification occurred in Canada's Parliament in December 2004 when the federal government agreed to reduce Canada's emissions to below 5.8% of the 1990 levels by the 2008-2012 time frames. Critics continue to state that this Accord was ratified by Canada without an adequate plan in place to meet the target. In addition some industries felt that they were not consulted adequately prior to the federal government ratifying this agreement.

Negotiations had been very intense over a period of years because the developing countries, including China and India, felt that the Western countries had profited well by developing their economies on cheap fossil fuels. They believed that the developed countries should take early action since they had caused the GHG emission problem initially.[1]

The US felt that their economy would be severely penalized by implementing CO_2 reductions since cheap energy provides them with a competitive advantage. In addition, they felt that there was not complete scientific agreement that GHG emissions were responsible for the recent sharp rise in global temperature. Germany and the UK were well positioned to sign the accord since the former had shut down many inefficient plants in the former East Germany. The latter had significantly reduced CO_2 emissions by using North Sea gas, instead of coal, in recent years[1]. In Canada, Alberta felt alienated since the economy is heavily dependent on fossil fuels and the future of the province was highly dependent on oilsands development. Debates continued in Canada and around the world, but negotiations continued since it appeared that there was public support in most developed countries for an agreement of this type of emission reduction.

The Accord was on the brink of failure after the US refused to ratify it. The Accord could only become "legally binding" if 55 or more countries signed it, representing 55% of global CO_2 emissions. Pressure was on the Commonwealth of Independent States to participate in order to make the Accord international law since the US, with 25% of the world's CO_2 emissions, refused to sign the Accord. After several negotiations, the Commonwealth of Independent States agreed to ratify the Protocol, and the final hurdle was overcome.

Alberta is a resource based province and is very dependent on oil, gas, and oilsands activities, and compliance with this accord would pose significant challenges to a very vibrant provincial economy. Major objections and representations were made to the Federal government against signing the Kyoto Accord; however, there is a significant level of local support for energy conservation initiatives. As an example, the City of Edmonton is committed to significant reductions in energy use and has set aggressive targets for itself. The transit system run by the City of Calgary purchases wind power to drive the light rail transit system as a gesture to support environmental cleanup measures that the City has undertaken. Okotoks, a small town in Alberta, is building a new housing development that is focused on solar power and energy conservation in order to be a model in the community. Although there appears to be opposition to Kyoto by the Province, some major municipalities of Alberta are showing support of the principles of the Kyoto Accord and have already developed targets for GHG reduction in their operations. The underlying principles of Kyoto include energy conservation, which has enjoyed support in various communities across the Province.

THE SCIENCE

The earth absorbs solar radiation and releases some of this back to space to maintain a reasonable equilibrium. Greenhouse gases, which include carbon dioxide, methane and nitrous oxides, assist in minimizing the amount of heat radiated back to space. Changes in the earth's temperature variation over specific time periods are shown in the U.N. Intergovernmental Panel of Climate Change (IPCC) graph (Figure 1)[2].

Greenhouse gases identified by the Kyoto Protocol include 6 major contributors to global warming. These are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFC's), perfluorocarbons (PFC's) and sulphur hexafluoride (SFC). Carbon dioxide is considered the major contributor and represents 64% of global warming effects followed by methane at 20%. Methane is 21 times more effective in terms of retaining heat, but remains in the atmosphere for 3 orders of magnitude less time than carbon dioxide. Other contributors such as SF6 are highly effective (at up to 11000 times that of carbon dioxide) in retaining long wave radiation, but they are produced in smaller quantities and are more controllable at their source.

Anthropogenic (man-made) emissions of CO_2 represent only 3% of total carbon dioxide generation, but the problem is that this net CO_2 cannot be absorbed fast enough in the environment and so the concentration has increased from 227 ppm to 370 ppm within the last 100 years. It is believed that this higher concentration has played a major role in global warming and the effects are significant. Major excursions in temperatures have occurred in several parts of the world, and 9 of the 10 warmest years on record (since 1850) have occurred since the late 1980s[1].

The effects of higher average global temperatures would raise ocean levels, cause flooding in many low lying areas in the world, increase the rate of polar and glacial melts, cause more severe weather patterns, affect migration of animals, and shift pest infestations and disease in areas where they were not common previously. Some have called global warming the most urgent crisis of our time since most countries cannot adapt rapidly enough to the major changes that would occur.

FOSSIL FUEL UTILIZATION

Fossil fuels currently power more than 85% of the world's energy requirements. It is not likely, or feasible, that fossil fuels can be eliminated from the energy mix because there is still an abundance of coal, oil, oilsands, and natural gas that will continue to be used for several more decades. Nuclear energy and emerging technologies cannot make up the near-term shortfall in energy requirements. In addition, the economy of several countries is too dependent on these resources to curtail their usage in a short time.

Coal fired power plants represent a significant portion of power generation facilities worldwide. It is interesting to note that Ontario has committed to shutting down coal fired power plants by year 2015. It is not known yet what technologies can make up the future shortfall when coal will be eliminated from the power generation mix in Ontario. Current prices of natural gas reduce Ontario's options while they continue to explore good alternatives to replace the future elimination of coal fired power generation.

Nuclear facilities continue to be shut down in Europe, and there is little chance of new nuclear power stations being permitted and built in North America within the next decade, although a recent initiative has been taken by the US government to add more nuclear plants to their energy portfolio.

The bulk of GHG emissions come from the use of fossil fuels for transportation, power and industry. Transportation and power industries represent significant generators of greenhouse gases. In recent years there had been an increasing demand for "Sport Utility Vehicles" (SUVs). The high price of fuel is now reversing the trend and it is hoped that GHG emissions will be reduced in the transportation industry in the years ahead with the increasing use of smaller commuter vehicles, and more environmentally sensitive engine designs.

Power from coal around the world and the rapidly growing economies of China and India will continue for several more decades, notwithstanding some public objections. There are over 800 coal fired projects in planning and development stages around the world and these could significantly increase GHG emissions. The US and China will continue to exploit the abundant supplies of coal in their countries, and it is expected that newer plants will have a significant amount of emissions control equipment to appease regulators and the public.

POTENTIAL SOLUTIONS

Carbon dioxide emissions will continue to rise in the years ahead with growing populations, and their energy use, if no steps are taken in the short term. A number of ways to reduce CO_2 emissions have already been implemented. These include plant and engine improvements, fuel switching from high carbon fuels to low carbon fuels, and renewable energy for power generation. The rise of wind energy generation has been very encouraging, as has been the use of supplemental solar power for various industrial applications. However, knowing that there will be continued use of fossil fuels due to their low costs and abundance, the most attractive option is to capture carbon dioxide from power stations and to utilize, or store, captured CO_2 in a suitable manner.

There are a number of viable CO_2 capture technologies. These include Amine Scrubbing, Membrane Capture, Oxyfuel Combustion and Cryogenic Separation. Amine scrubbing has been well used by the oil and gas industry for many years and acid gas (carbon dioxide and hydrogen sulphide) removal is a very mature process used by many energy companies. Capture plants for CO_2 are currently in operation around the world and have had good success. Membrane capture has also been demonstrated and will continue to evolve favourably in the years ahead. Oxyfuel combustion has been demonstrated and is expected to be utilized in the medium term. Cryogenic capture plants have already been demonstrated for many years and can be adapted for CO_2 capture. At present, the leading technology for CO_2 capture appears to be Amine Scrubbing since these processes are currently in operation at commercial plants albeit in smaller sizes.

Once CO_2 is captured, it needs to find a market. One of these markets is Enhanced Oil Recovery (EOR). Since 2004 the Weyburn Enhanced Oil Recovery project in Saskatchewan is one of the most studied projects for reviewing the success of CO_2 utilization and storage. This project purchases CO_2 from a Synfuels plant in North Dakota and transports the captured gas 330 km through pipelines to a miscible flood project in Weyburn Saskatchewan. This EOR project is earning money for the owners and is allowing various companies to study the effect of long-term CO_2 storage. The Statoil Project in Norway is another good example of CO_2 storage project developed in response to a CO_2 tax. It made sense to store CO_2 under the ocean bed rather than release it to atmosphere.

EOR projects are an excellent way of storing CO_2 and increasing yields from depleted oilfields. Unfortunately, not all oilfields are suitable for miscible flood and EOR projects provide a very small storage capability for all the CO_2 that is currently generated in power production. The sale of CO_2 within the food, beverage, and fertilizer industries is too small a market for the large amounts of CO_2 currently generated.

Ocean sequestration (storage) had been of interest initially but had met with significant public opposition in North America and Europe. A better alternative being studied is "permanent" land storage in the Western Sedimentary Basin and other areas in North America where the geology lends itself well to CO_2 storage. At this time, it appears that this is the only major alternative for storage of large amounts of CO_2 captured from large emitters.

Storage or transport of carbon dioxide must be done in a safe manner[3]. Public perception is that CO_2 is relatively safe since it is encountered in so many aspects of normal life. However, in concentrations as low as 8%, it can be fatal. As an example, a major incident in Cameroon in 1986 resulted in the deaths of many people and animals when a volcanic lake released naturally occurring CO_2 into a valley. It is events such as this that will ensure that industry will exercise diligence in the construction of CO_2 capture and transport facilities.

Fossil Fuels in Power Generation

The power generation industry is currently comprised of coal, oil, natural gas, hydroelectric, and nuclear power plants as major players. Wind, solar, and other technologies are emerging, but these alternatives cannot provide large blocks of power needed to replace retiring coal fired plants, nor can they compete with the reliability benchmarks of base loaded large power generation facilities. Safety issues related to nuclear plants is still an outstanding issue.

Coal represents the greatest percentage of fuel for power generation due to its abundance and low cost in developed and developing countries. Improved efficiencies in coal fired power plants with supercritical steam cycles and in advanced gas turbines have allowed some reduction of CO_2 in the stack gas. Other technologies could develop improved efficiencies and lower costs.

Environmentalists are still awaiting an acceptable level of safety for spent nuclear fuel rods and nuclear plant safety before replacing coal fired plants. Other technologies need to be improved considerably more before they can replace coal and natural gas as major suppliers of power. These technologies need to compete with the cost of power, efficiency and reliability of base loaded power plants, which industry and the public has taken for granted for many years.

The Role of the Gas Turbine

Significant supplies of coal in North America made coal the obvious choice for power generation. Gas turbines had not been used as much since it was believed that a premium fuel such as natural gas should only be used for home heating. This viewpoint changed in the last decade when it was found that gas turbines could provide relatively inexpensive, clean power in many locations. Permits were relatively easy to obtain for these gas turbine power plants compared to coal or nuclear plants, and construction lead times were much shorter due to the ability to modularize the units.

CO_2 Reduction

Over the years gas turbine efficiency has increased appreciably and combined cycle efficiencies are approaching 60%. In the Kyoto world, the gas turbine based power plant is attractive when compared to conventional coal fired plants. GHG emissions are considerably lower since most of the energy, approximately 60%, is derived from hydrogen in the fuel as opposed to carbon in coal.

Even taking into account full cycle GHG emissions reduction, it has been estimated that for a specific gas fired cogeneration plant, CO_2 emissions are 420kg/MWhr as opposed to 1000-1200 kg/MWhr from a coal-fired plant[4]. A 400MW coal fired plant produces approximately 8000 tons/day of CO_2 as opposed to a 400MW gas turbine plant, which produces approximately 3000 tons/day of CO_2. Since CO_2 is regarded as one of the most critical greenhouse gases to control, it can be seen that this reduction is a significant benefit in the Kyoto world.

A 400MW coal fired plant could be penalized even further if CO_2 capture were to be installed to be competitive with gas turbine generation. The capture plant could consume as much as 100MW of parasitic power to take the CO_2 out of the base plant and the capture plant. Equipment in the capture facilities includes absorbers, pumps and compressors, which become much larger and require a larger plot space for the dilute CO_2 stream.

There are ways for the coal fired plant to reduce parasitic losses by integration of CO_2 capture into the facility. However, at first glance, the gas turbine does offer a very attractive option when considering the lower amount of CO_2 generated when compared to an equivalent coal fired plant.

NOx Reduction

NOx, primarily Nitrous Oxide (N_2O) is a significant greenhouse gas in addition to being a major contributor to smog. These emissions from gas turbines have reduced over the years while costs of the units have not increased considerably due to the implementation of dry low NOx combustors. These emissions have been reduced from over 300 ppm to 25 ppm in the larger industrial machines and 40ppm in the smaller units with the continued development of dry LoNOx combustors. This development was also assisted by the elimination of water injection in the combustors thereby conserving a large amount of water which has significant costs associated with it. NOx emissions from a gas turbine power plant compare very favourably with those produced from a coal fired plant.

GASIFICATION PROCESSES

Gasification is a partial oxidation process that effectively separates carbon from high carbon feedstocks and also produces hydrogen. The process uses high temperature, high pressure steam to convert the feedstock to the desired components while limiting the amount of oxygen in the gasifier reactor. This process eliminates the burning of coal and facilitates capture of particulates, sulphur and NOx. Carbon dioxide is produced in high concentrations, which allow it to be captured economically as opposed to having a separate capture plant.

Gasification of low value fuels has been evaluated many times over the years but has not been competitive when oil was priced below $20/barrel. However, facility owners who have been storing a large amount of low value fuels can now consider gasification of this “zero value” fuel to produce hydrogen and electricity. There are several Integrated Gasification Combined Cycle (IGCC) plants around the world and gasification appears to be an attractive technology in a Kyoto world. The 300MW Polk Power stations in Florida and the Wabash River Coal Gasification plant in Indiana have been in operation within the last decade. IGCC demonstration plants have been in operation in the Netherlands, Spain and Italy. It is anticipated that IGCC plants will be built in China to produce power and hydrogen for their industrial facilities.

Gas turbines are an integral part of these plants, and it is expected that more gasification projects will built in the medium term.

HOT WINDBOX REPOWERING

In this process the burner windbox of a coal-fired plant is configured to accept hot combustion gases from a gas turbine. An increase in efficiency and a reduction in NOx and other emissions is an advantage. There is, however, a need to make some major changes to equipment and ducting in the existing facility which may be costly and not worth pursuing.

PEAKING SERVICE

Large coal fired base load plants normally take several hours to startup and may emit higher than normal emissions during this period. It is an advantage to use aero-derivative type gas turbines to supplement peak power requirements rather than bring on a larger coal fired unit and operate it at part-load to handle the demand during peak hours. The reduction in NOx, SOx and CO_2 can be significant when this is done and appropriate control is in place to dispatch these units when needed.

ALTERNATIVE FUELS

Industry can expect to see the gas turbine evolve further as a “green machine” to burn more synthetic fuels derived from coal, bio-mass, or other low value fuels. Current challenges for burning low BTU syngas include modified combustor design to improve NOx emissions for these low value fuels. The larger fuel/air ratio for these combustors, as compared to natural gas, introduces some complexity that needs to be addressed over a range of operating conditions. The ability to adapt the gas turbine to burn a variety of fuels has already been demonstrated. Natural gas and distillates have been used in the past for industrial applications and power generation.

CURRENT PUBLIC/PRIVATE INITIATIVES

The Canadian Clean Power Coalition (CCPC) is a Canadian led initiative evaluating various technologies that can be used for power plants of the future. FutureGen, a US DOE initiative, is also looking at clean burning technologies that will be applied to their power plants in the future. Both these initiatives for the future include gas turbines as one of the key pieces of equipment in their power plants. Like Canada and the US there are other countries that will utilize this industry workhorse and maximize its use in power generation, industrial applications, district energy systems and co-generation systems as part of the program to reduce emissions and safeguard public health.

CONCLUSION

The Kyoto Accord is only the first step in mitigating the effect of global warming, and benefits will not be seen for another 5 decades for measures taken in the next few years. It is, however, an important first step and it is encouraging that so many countries, with such diverse agendas, were actually able to come to an agreement such as the Kyoto Accord, which has such a major impact on their economies. Although the United States has not participated in the Accord at this time, it is one of the leading countries to research technologies for carbon emissions reduction and to announce aggressive programs for development of improved technologies for power and transportation.

A current challenge for gas turbine application is the high cost of natural gas, which is likely to continue for several more years. The high cost is adversely affecting short term application of these units for power generation. Currently, several major gas turbine units for power generation are sitting idle since it is too expensive to operate these because of high fuel costs. It is hoped that Liquified Natural Gas (LNG) production and distribution, and alternative low cost fuels, will once again make these units a competitive energy producer.

In a carbon constrained world, the gas turbine will continue to be a very strong competitor when compared to other types of power plants. Gas turbines are widely used, have evolved favourably over a number of years, have worldwide applications onshore and offshore, and are well known to operators around the world. There are ongoing developments which will assure greater fuel diversity for gas turbines to allow greater utilization in Integrated Gasification Combined Cycle (IGCC) plants. These plants are currently viewed as a more environmentally friendly alternative to coal-fired plants but there is still considerable work to be done to win over new users.

The future for gas turbines in a Kyoto constrained world continues to look very attractive in the years ahead. Use of lower grade, inexpensive fuels will allow gas turbines to provide power to industry to compete effectively against other technologies, while providing the benefit of reduced carbon dioxide emissions. Gas turbines will continue to be viewed as “green machines” and will be an integral part of power generation for many years into the future, with the continued developments related to improved efficiencies leading to lower CO_2 production and improved dry low NOx combustors. Manufacturers continue to develop gas turbines with higher firing temperatures, enhanced materials and processes, effective blade cooling, and longer life. All of these advances and their environmental benefits will ensure the continued use of gas turbines well into the future.

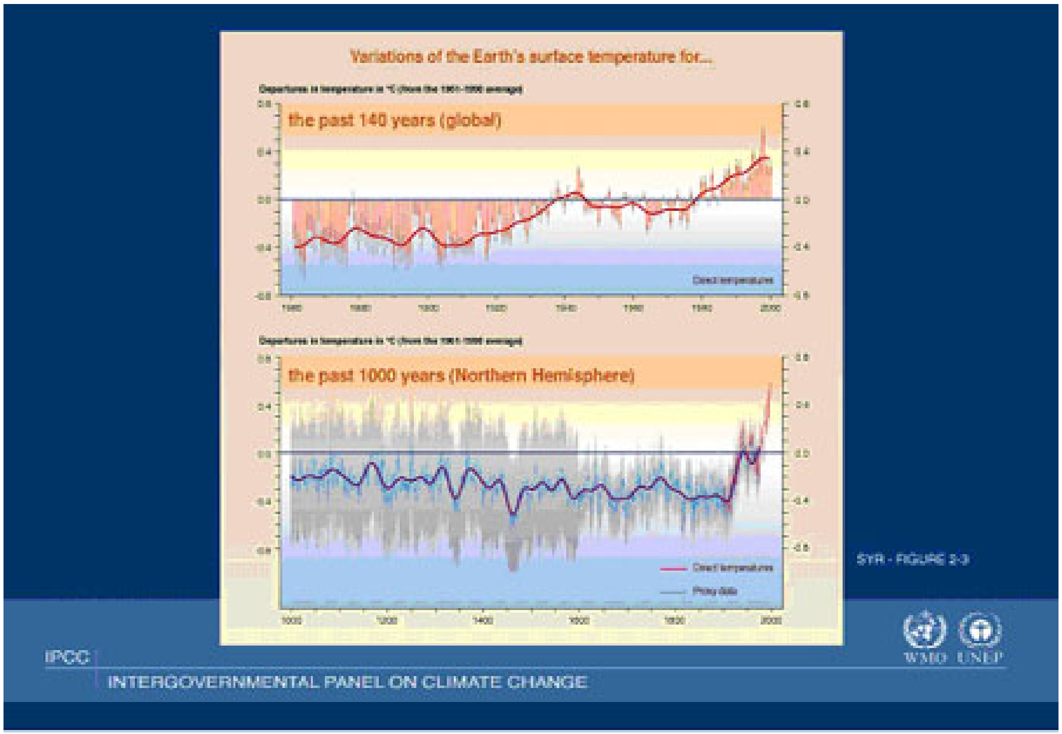

Figure 1 Earth's Temperature Variation

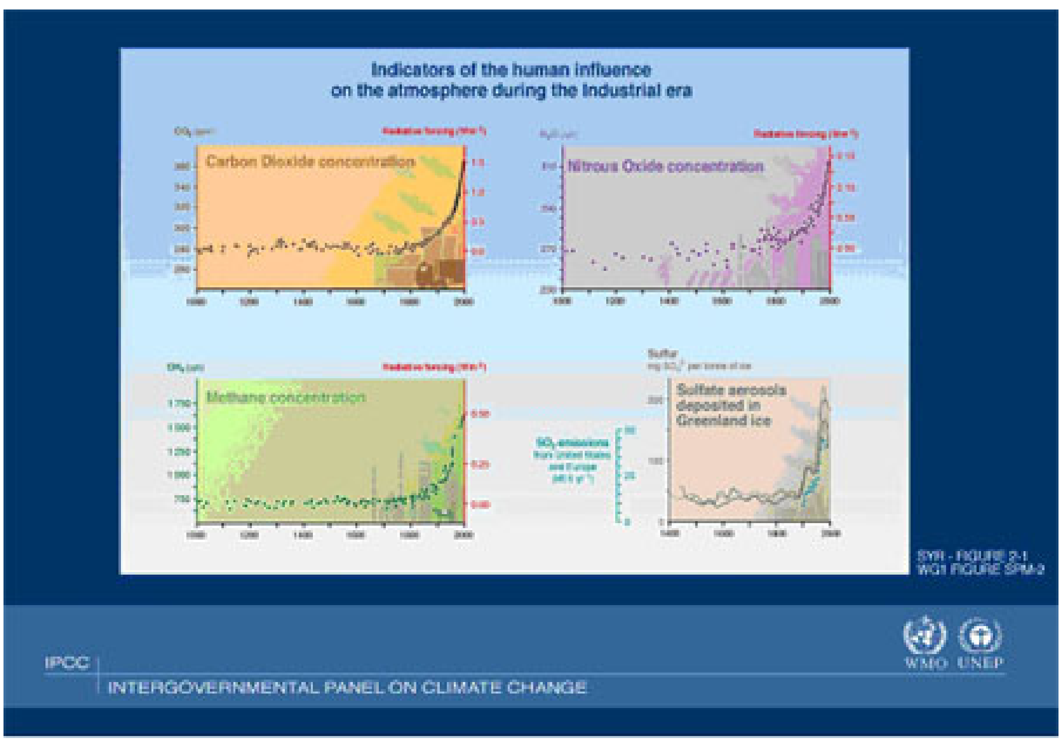

Figure 2 Human Influence

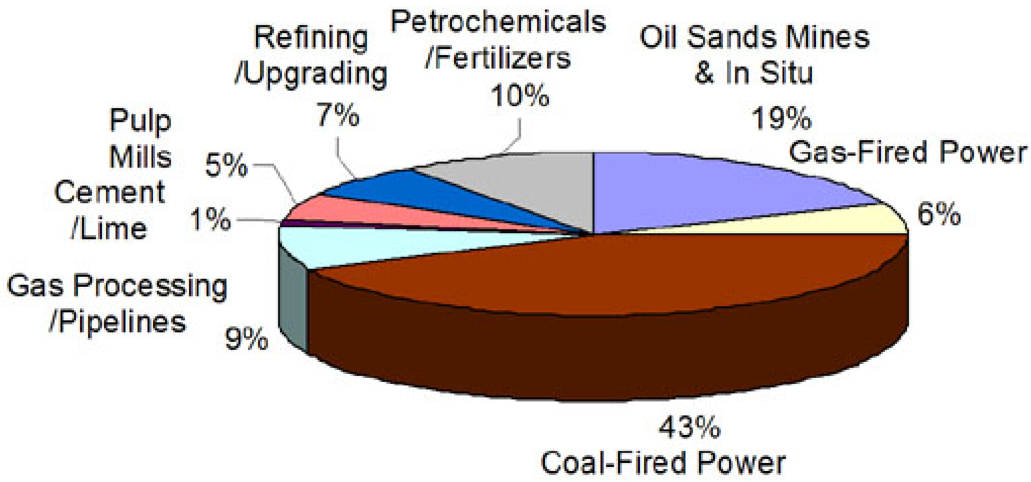

Figure 3 CO_2 Production by Industry

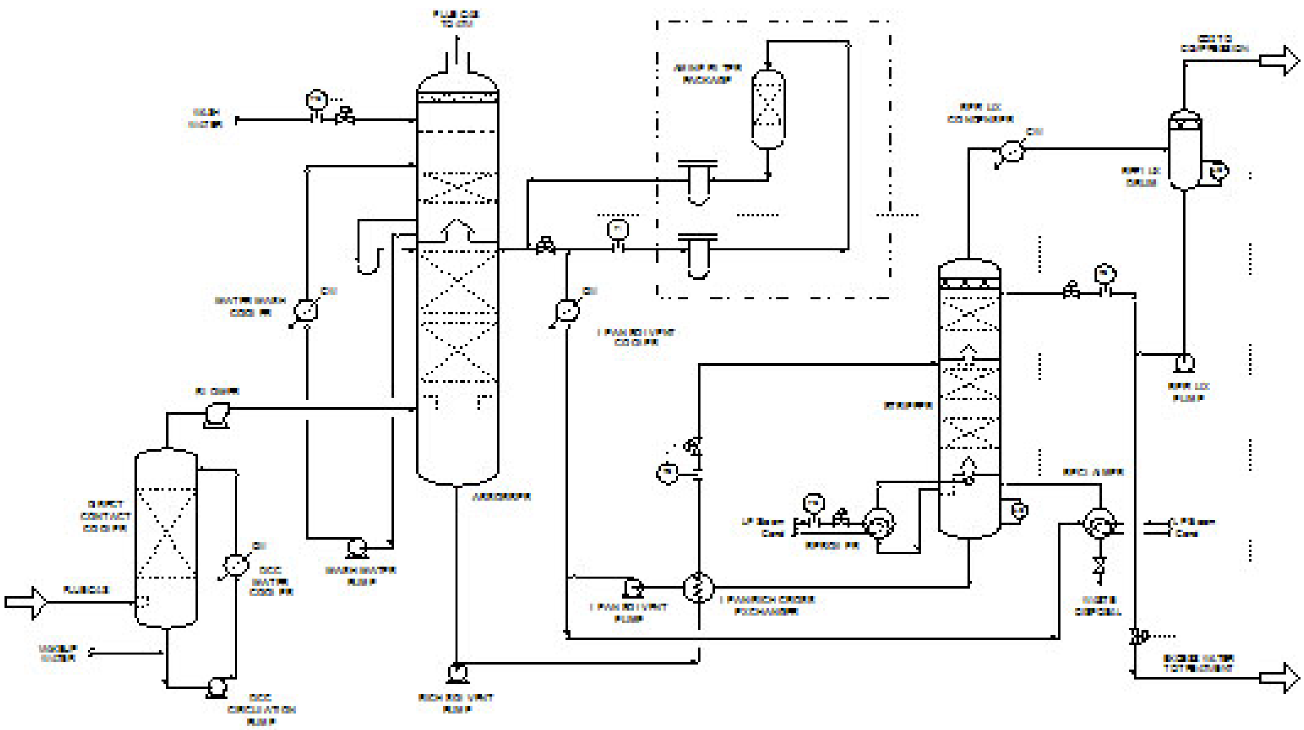

Figure 4 Basic Amine Scrubbing Plant – Fluor

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